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SWIMMING BIOPHYSICAL RELEVANT PARAMETERS EXTRACTED FROM VELOCIMETRY AND ACCELEROMETRY

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This paper presents different examples of the use of direct velocimetry and accelerometry for the biophysical evaluation and advice of swimmers, assessing relevant parameters for performance enhancement. The described techniques are easy to build and operate, and allow real- and useful-time feedback for practitioners. The velocimetric measurements were based on a cable speedmeter (*SwimSensor*), and the accelerometric ones using a 3-axial inertial central – *WIMU* –, incorporating both accelerometers and gyroscopes. Results include swimming intracyclic velocity fluctuations for technical feedback, spectral analysis of the $v_{(t)}$ function to depict bioenergetical anaerobic intensity zones transition and specific fatigue, and breaststroke gliding drag assessment using inverse dynamics.

KEY WORDS: Intracyclic velocity variations, hydrodynamic drag, alactic to lactic anaerobic transition

INTRODUCTION: Progresses in swimming training and performance are expected to be linked with increased training load and coach's expertise, but also to training and movement evaluation and advice. Scientific research and technologic developments in the field provided serious improvements in the intervention capacity in the field, particularly using real- and useful-time feedback for practitioners. In this paper we will present different examples of the use of direct velocimetry and accelerometry for the biophysical evaluation and advice of swimmers, assessing relevant parameters for performance enhancement: swimming intracyclic velocity fluctuations for technical feedback, spectral analysis of the $v_{(t)}$ function to depict bioenergetical anaerobic intensity zones transition and specific fatigue, and breaststroke gliding drag assessment using inverse dynamics.

METHODS: The first device used for these purposes was a cable speedometer, named *SwimSensor* (Lima et al., 2006). The *SwimSensor* is a simple and powerful system for swim speed evaluation and training advice. Its principle of operation is quite simple: a reel of thin nylon or Kevlar string is attached to a turn encoder and microcontroller which computes the instantaneous linear velocity (Figure 1). The nylon string is securely fastened to a belt worn by the swimmer at the waist level and unwound as he moves forward. The *SwimSensor* uses an incremental sensor with 500 points resolution per revolution of a reel without accumulated line. A brake engine allows the full system inertia to be insignificant, keeping the line always stretch. The computed velocity is sent by an USB connection to a host computer that performs several additional computations, namely:

(i) real time acquisition and display of velocity data;
(ii) recognition of breaststroke swimming technique;
(iii) calculation of mean velocity, simultaneously;

It also allows for synchronization with other equipments and biofeedback solutions.
Additionally, dedicated software was developed in NI LabVIEW® for data capturing and recording with a graphical user interface to facilitate interaction, post-processing and analysis. For the case of breaststroke, it provides:

(i) user selectable peaks and valleys on the velocity profile;
(ii) calculation of minimum, mean and maximum velocities;

(iii) Calculation of time duration and accelerations between peak and minimum values of velocity;
(iv) Calculation of mean breaststroke cycle duration, distance per stroke, mean velocity, and intracyclic velocity variation.

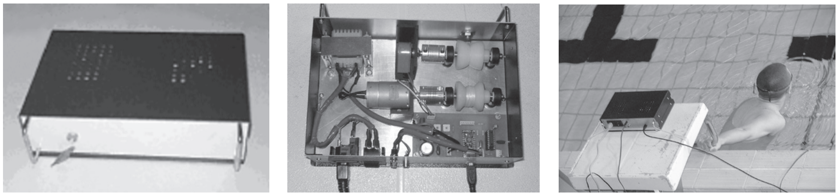

Figure 1: The cable velocimeter (speedmeter) – *SwimSensor* (Lima et al., 2006) – used in the studies reported in this paper.

Despite the quality of the results provided and the easiness of its use, the mechanical connection of the *SwimSensor* to the swimmer introduces some practical constrains, particularly noise induced by involuntary contacts with the line, and the effects of inclination of the line with the horizontal (two issues determining solving solutions of opposite directions). As a consequence, the next step forward would be the design of a wireless and wearable solution, based on accelerometric technology: the *WIMU – Wearable Inertial Measurement Unit*. The *WIMU* is a MEMS-based wearable device for assessing biomechanical parameters of a swimmer and consists of a 3-axial accelerometer, a gyroscope, a microcontroller and a power supply unit. The acceleration and angular velocity signals are acquired and converted sequentially by the 10-bit ADC integrated in the microcontroller. A time-stamp is then retrieved from the system and added to a sensor packet containing the 3-axis accelerations and angular velocity. Therefore, the final packet frame consists of sensor signals together with a time-stamp, which is then ready to be sent by radio frequency to a remote station where the sensor data can be analysed and processed (Silva et al., 2011). In this study, the sensor was placed on the upper back of the swimmer as can be seen on Figure 2.

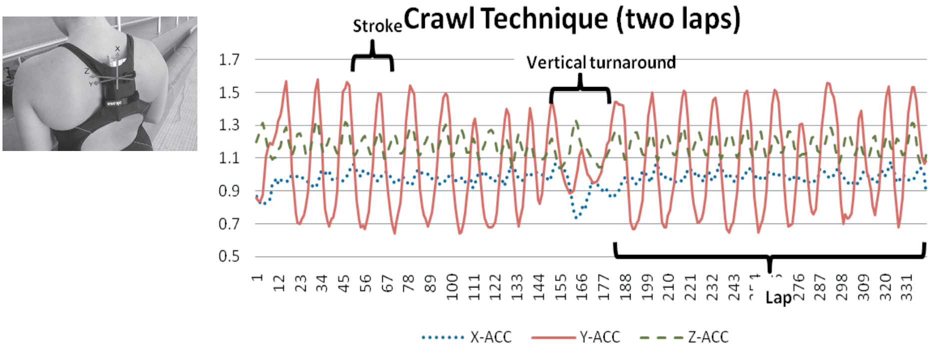

Figure 2: Two laps of velocity to time variations using the crawl swimming technique. Signals acquired from the *WIMU*. Adapted from Silva et al. (2011).

RESULTS AND DISCUSSION: The signals recorded with the *SwimSensor* and the *WIMU* are presented bellow. Figure 3 shows a typical breaststroke $v_{(t)}$ relationship. These kind of records allow swimmers and coaches to analyse and objectively base technical alterations proposed to each specific subject, particularly considering the relative importance of the leg or the arms actions, as well as, the minimum velocity values associated with the recovery phase, particularly the recovery of the legs. The instantaneous velocity values can also be provided to the swimmer and coach through acoustic concomitant feedback. They can also be overlapped to video images and used for subsequent analysis of swimming actions.

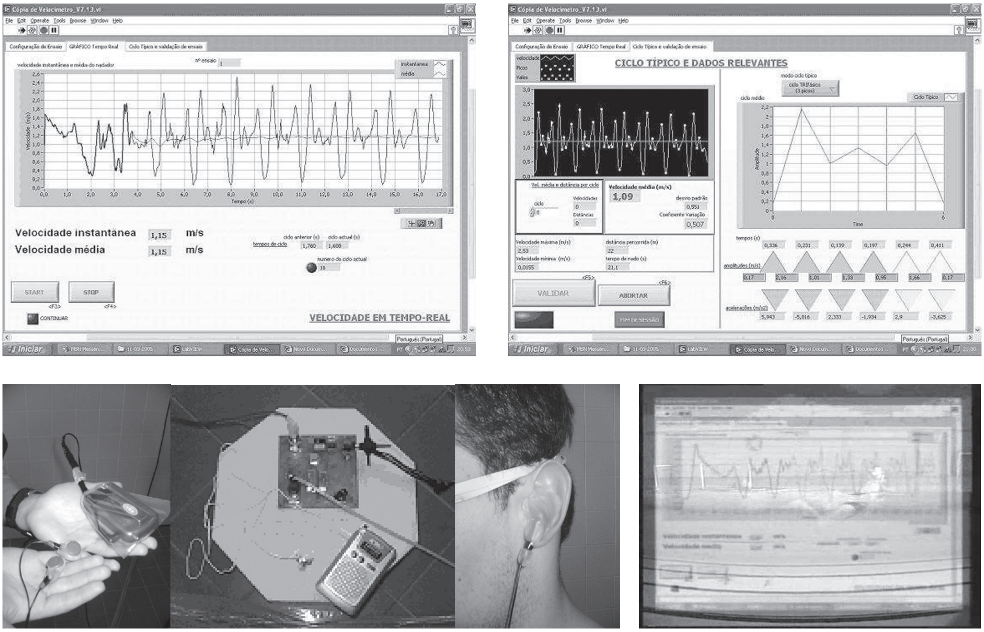

Figure 3: Examples of an output of the *SwimSensor* for breaststroke analysis. On the superior left panel the instantaneous and mean velocity profiles, and in the right side the stroke cycle model with the recognition of a bi- or tri-peak technique, the intracyclic velocity variation index, durations, mean velocities and accelerations, and critical values of velocity and time of the different phases of the breaststroke cycle. Velocity can be real time transmitted as a acoustic signal, and mixed with video for ulterior analysis of swimming technique (Lima et al., 2006).

The same device can also be used for fatigue assessment and evaluation of anaerobic metabolism transition. The two approaches were already tried in this domain: a slope of peak velocity values during a specific distance maximal sprint test (Abraldes et al., 2007), and the identification of a clear frequency spectrum change during the same test using wavelets (Soares et al., 2006) - Figure 4.

These fatigue biomechanical performance indicators of different bioenergetical systems were associated with the Wingate power test and also with delta blood lactate values registered between different phases of a 50 m sprint test (Soares et al., 2008). Moreover, the threshold behaviour of the $v_{(t)}$ function was also shown to be sensitive to maturation and training experience (Soares et al., 2010). In the case of the example presented in Fig. 4, the threshold transition was observed corresponding to an exercise duration of just below 11 s.

Finally, $v_{(t)}$ values can be used to compute velocity decay (negative acceleration) during gliding phases, traducing the particular drag effects during those phases. This was previously tried after breaststroke turns, considering the two characteristic gliding positions (Vilas-Boas et al., 2010) – Figure 5.

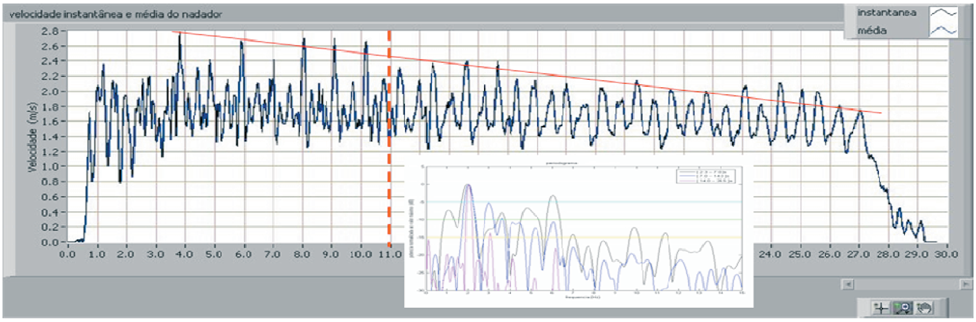

Figure 4: Wavelet spectral frequency analysis of the $v_{(t)}$ variation during a 50 m maximal front crawl test and the regression slope analysis of this sprint specific fatigue index.

Drag (D) can be measured by inverse dynamics knowing acceleration (a) during a given glide and the swimmer's body mass (m), using the equation of motion:

$$D = m \cdot a \tag{1}$$

Drag coefficient (C_D) values can be also estimated after computation of the body cross sectional area (S) using the Newtonian drag equation, where ρ is water density and v the body velocity:

$$D = 0.5\, \rho\, C_D\, S\, v^2 \tag{2}$$

In the study of Vilas-Boas et al., 2010, S values were measured through planimetry analysis of calibrated photos obtained on the transverse plan of the swimmers.
The final results provided by inverse dynamics showed to be very coherent with Computational Fluid Dynamics (CFD) approaches for the same problem (Marinho et al., 2009; Costa et al., 2010).

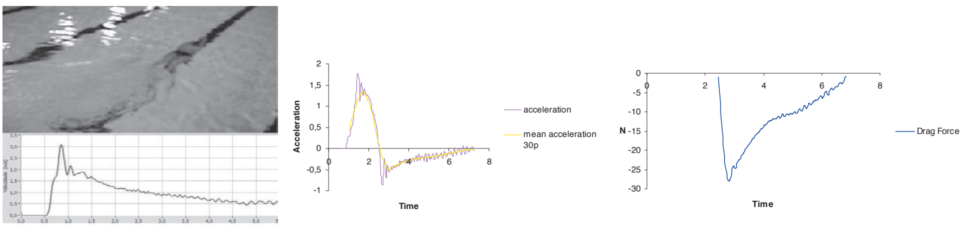

Figure 5: Velocity to time curve (left) acceleration(middle – numerical derivative of velocity) and calculated body drag (right),

CONCLUSION: Velocimetric and accelerometric devices, if possible wereable, like WIMU, should be considered biophysical relevant tools for swimming training evaluation and advice, both allowing strictly technical and biomechanical, but also bioenergetical, relevant parameters. Moreover, they allow an integrated approach to swimming performance, which are considered to be scientifically and pedagogically usefull for the progress of knowledge and of the daily professional activity of technitians, particularly coaches.

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